



Arctic coupled ocean – sea ice state estimates: a forward approach

An T. Nguyen^{1,2}, Dimitris Menemenlis², Ron Kwok²

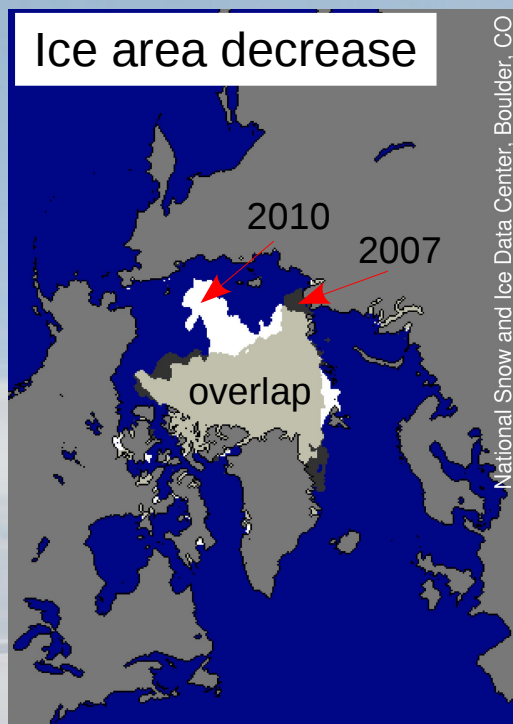
¹JIFRESSE, UCLA, Los Angeles, CA, USA

²JPL, Caltech, Pasadena, CA, USA

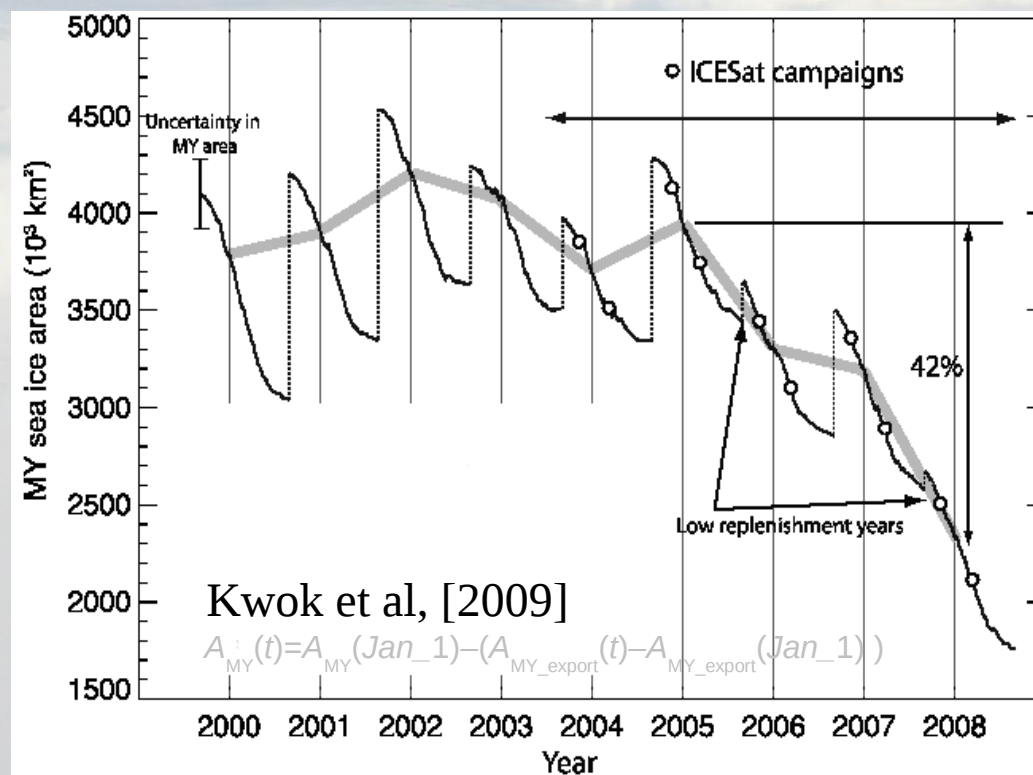
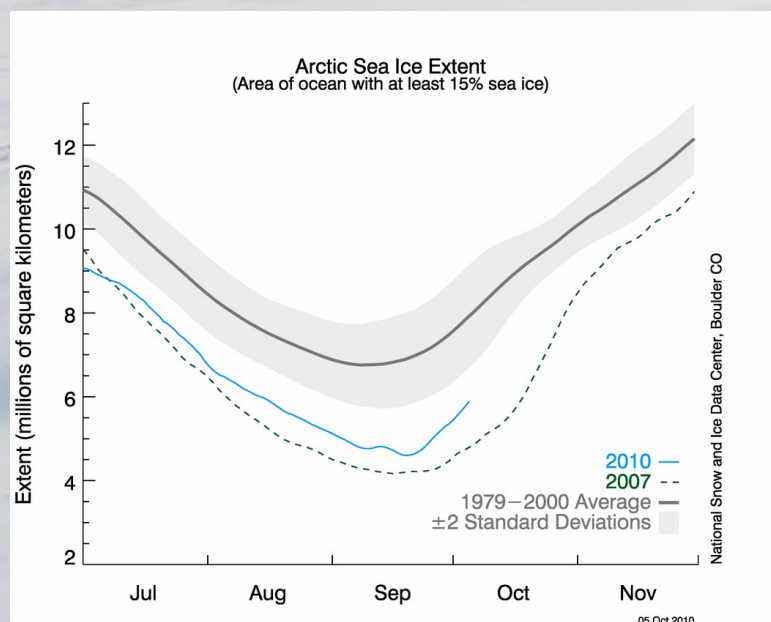
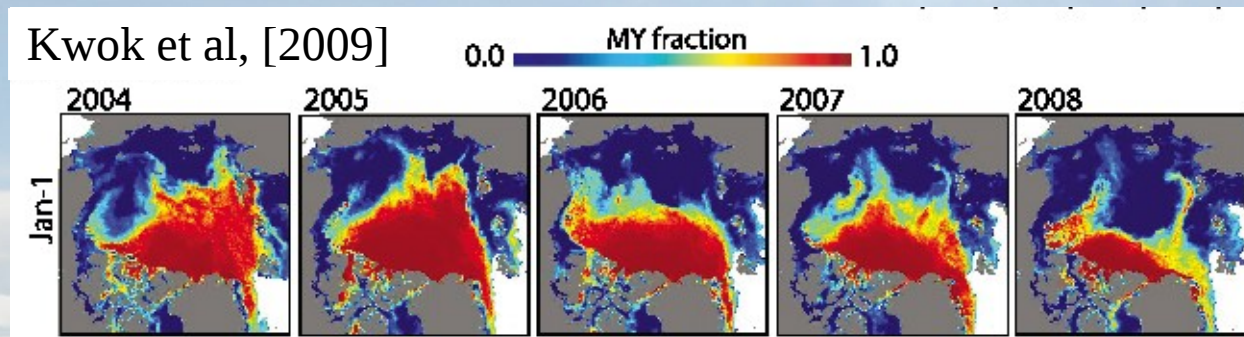
Outline

- Introduction
 - Recent changes in the Arctic Ocean
 - Current modeling effort – AOMIP
 - Why the need to assess current Arctic simulation
- MITgcm
 - 1992—2008, global / regional
- Data
 - Sea ice, hydrographic
- Assessment
 - Cost reduction
 - Recent trends
 - Remained systematic differences
- Future direction
 - ASTE: Eddy-Permitting Arctic & Sub-Polar North Atlantic State Estimate
 - Comprehensive effort: Adjoint solution

Introduction – recent changes in the Arctic Ocean

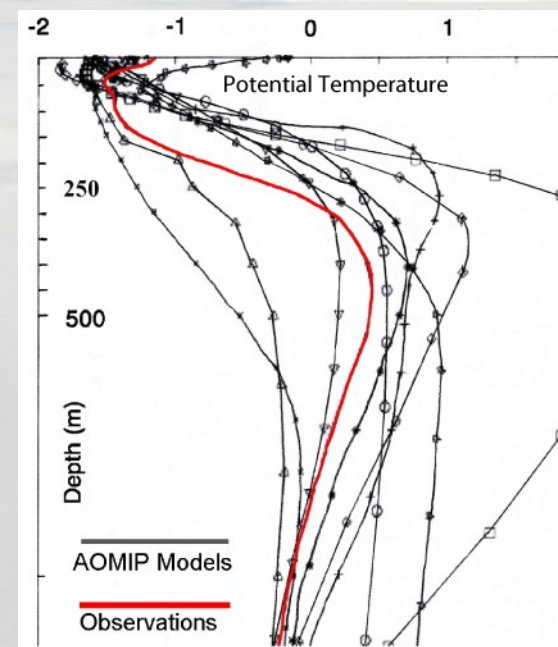
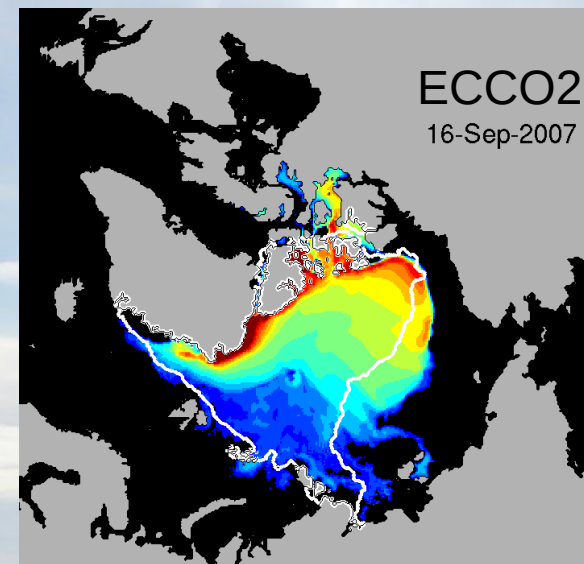


Multi-year ice (QuikSCAT) decrease

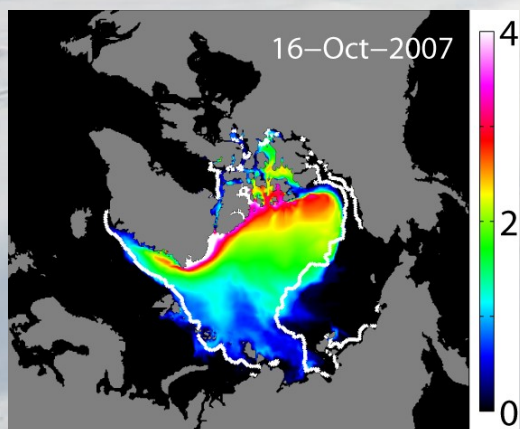
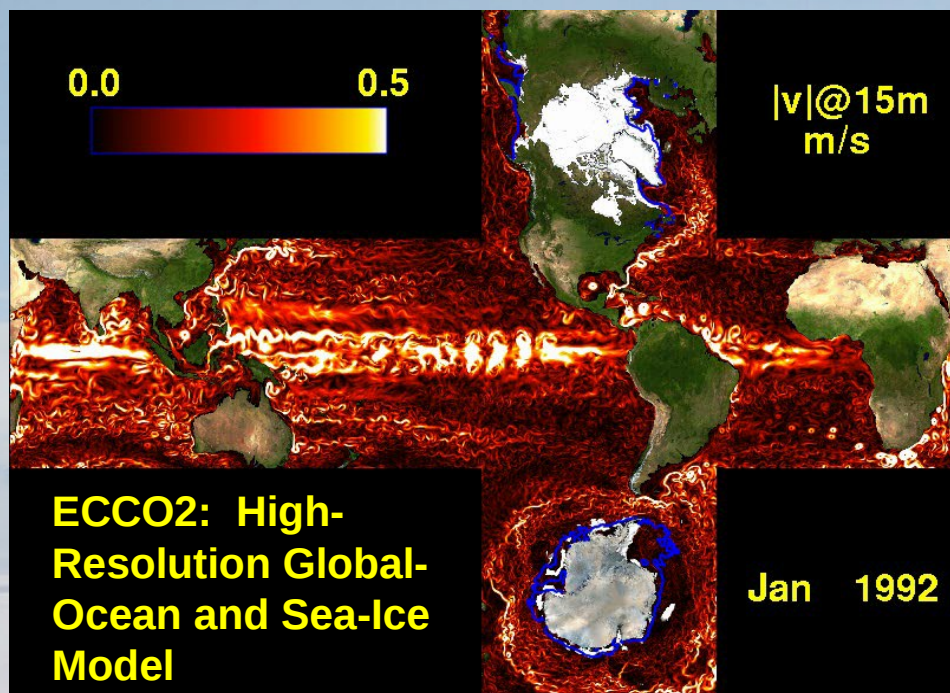


Introduction – current modeling efforts

- AOMIP (Arctic Ocean Models Intercomparison Project)
 - Joint effort to address model deficiencies – Phase I
 - Process studies – Phase II
 - Model – model comparisons, model-data comparisons
- Data assimilation
 - Sea ice, *e.g.*, *Harder and Fischer [1999]*, *Zhang et al. [2003]*, *Miller et al. [2006]*, *Lindsay and Zhang [2006]*, *Stark et al. [2008]*, *Rollenhagen et al. [2009]*
 - Ocean, *e.g.*, *Nechaev et al. [2004]*, *Panteleev et al. [2010]*
- Motivation
 - “Best” representation of the Arctic couple ocean – sea ice model
 - Least-square, optimization
 - Model – data comparisons



[Holloway et al, 2007]



Ocean model:

- ~ 18km horizontal, 50 vertical levels
- volume-conserving, C-grid
- Surface BC's: ECMWF / ERA-40 based
- Initial conditions: optimized
- bathymetry: GEBCO
- KPP mixing [Large et al., 1994]

Sea ice model:

[Losch, 2010], [Heimbach, 2010]

- C-grid, ~ 18km
- 2-category zero-layer thermodynamics [Hibler, 1980]
- Viscous plastic dynamics [Hibler, 1979]
- Initial conditions: Polar Science Center
- Snow simulation: [Zhang et al., 1998]

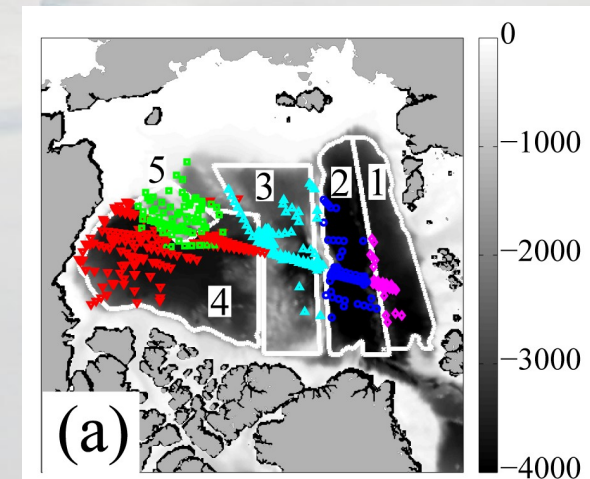
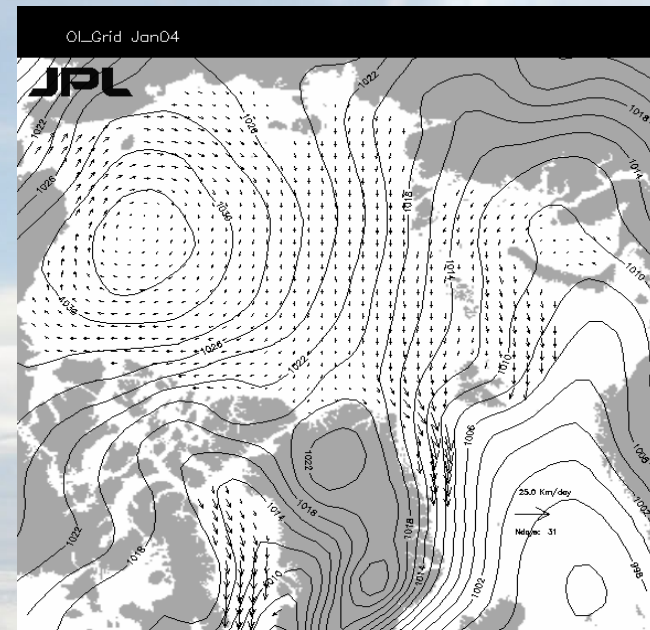
Data

- Sea ice

- Drafts, Rothrock and Wensnham [2007], Witte and Fahrbach, [2005], Kwok [2009]
- Drifts, Kwok et al. [1998]
- Fluxes, Kwok et al, [2004,2006,2009]
- Concentration – bootstrap, <http://nsidc.org>

- Hydrographic

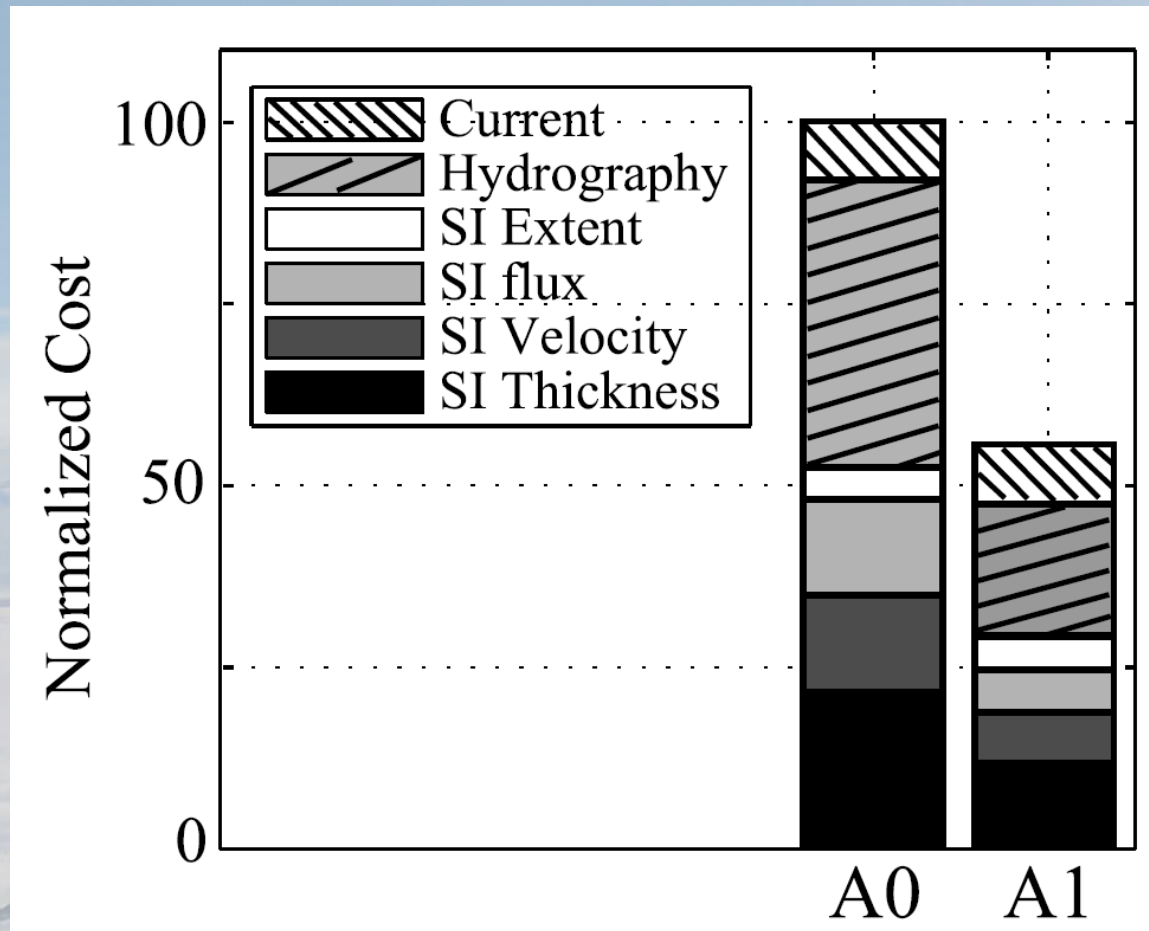
- CTD—SCICEX
- CTD—BGEF, Kemp et al. [2005]
- CTD—ASOF
- Fluxes, Fahrbach et al. [2001], Schauer and Fahrbach [2004], Woodgate and Aagaard [2005], Woodgate et al. [2006]



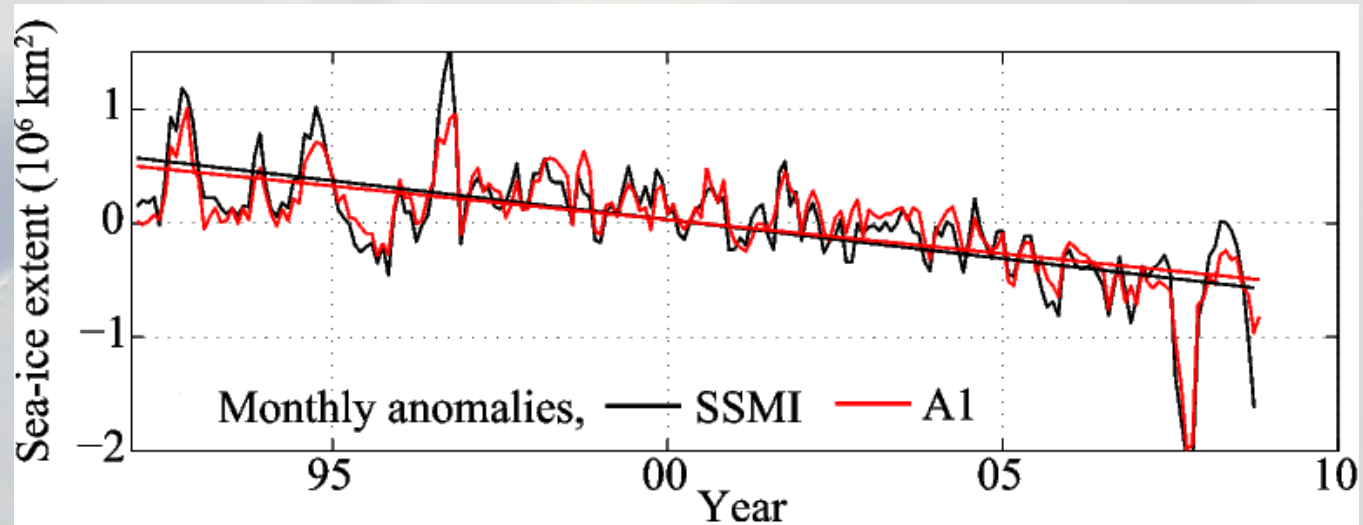
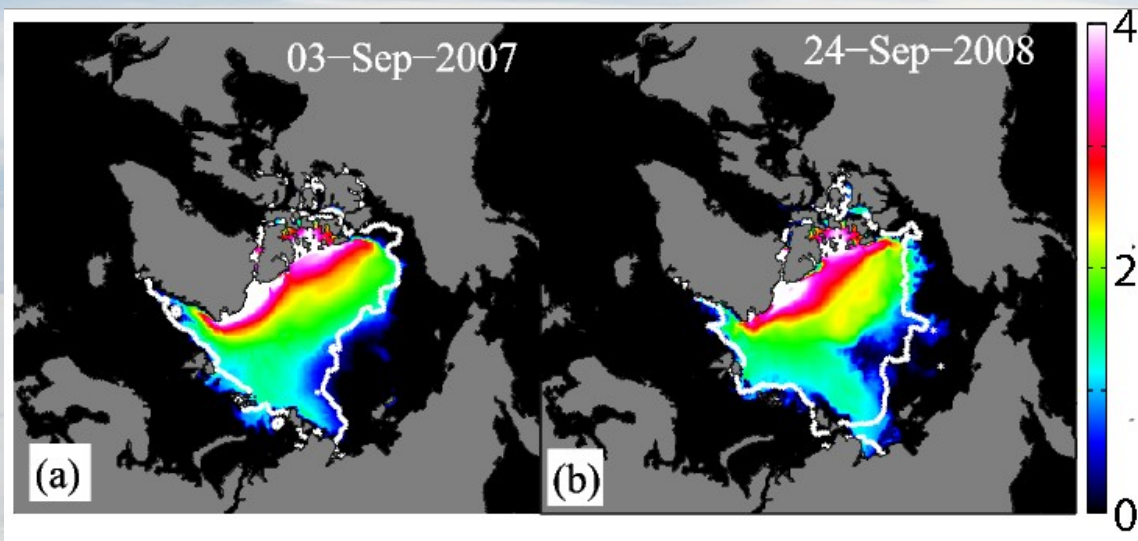
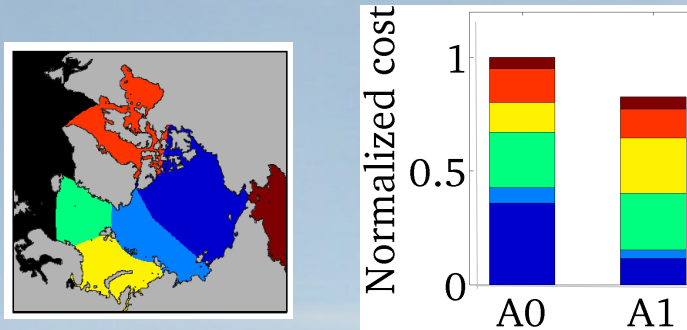
Model parameters η

Parameter	A0	A1	AOMIP ^a	Comment
Initial conditions	ECCO2	WOA05		Fields considered: PHC, WOA05, WOA01, WGHC
Atmospheric forcing	ECCO2*	JRA25		*based on ERA40/ECMWF
Ocean albedo	0.1507	0.1556	0.10	
Sea ice dry albedo	0.8783	0.7	0.6–0.75	0.73–0.83 in CCSM ^b
Sea ice wet albedo	0.7869	0.7060	0.5–0.68	≥ 0.655 in CCSM 0.4–0.6 in <i>Curry et al.</i> [2001]
Snow dry albedo	0.9686	0.8652	0.80–0.84	0.96 in CCSM 0.84 in <i>Curry et al.</i> [2001]
Snow wet albedo	0.8270	0.8085	0.60–0.77	≥ 0.86 in CCSM 0.77 in <i>Curry et al.</i> [2001]
Ocean/air drag	1.0185	0.9997		
Air/sea ice drag	0.002	0.00114	0.0011–0.0013	
Ocean/sea ice drag	0.0052	0.0054	0.0055	
Ice strength P^*	2.6780	2.2640	1.0–2.75	10^4 Nm^{-2}
Lead closing H_o	0.5	0.6074	0.25–0.5	
Vertical diffusivity	10^{-5}	5.44×10^{-7}		m^2/s
Salt plume	off	on		<i>Nguyen et al.</i> [2009]
River runoff factor	1	1.2472		factor \times ARDB ^c

Results – cost reduction

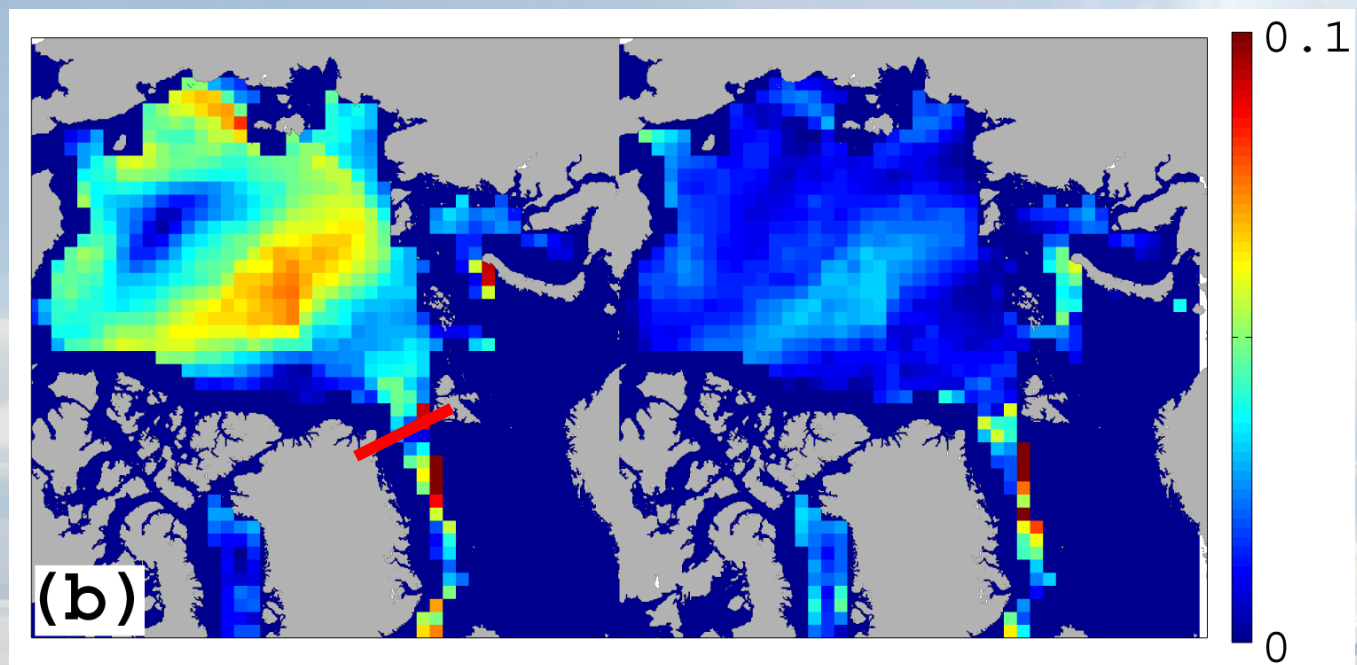


Results – sea ice extent

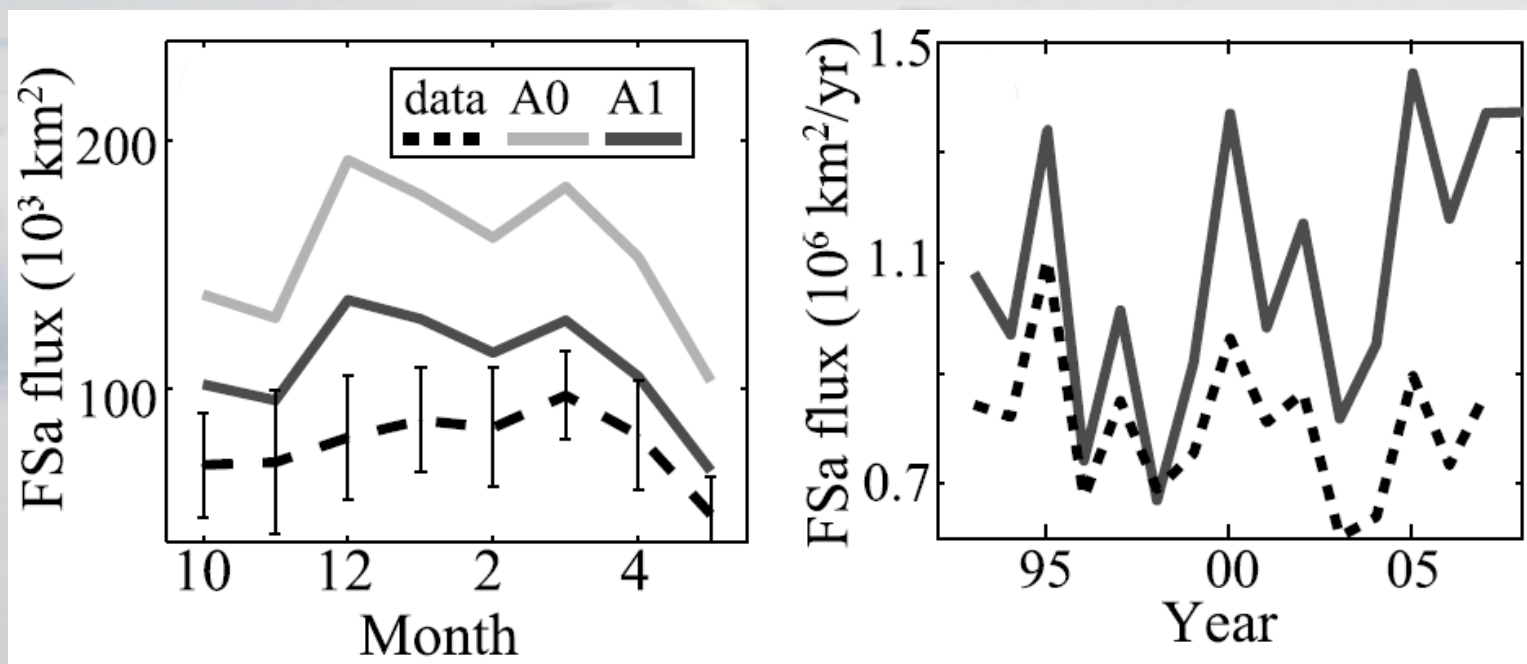


Results – sea ice

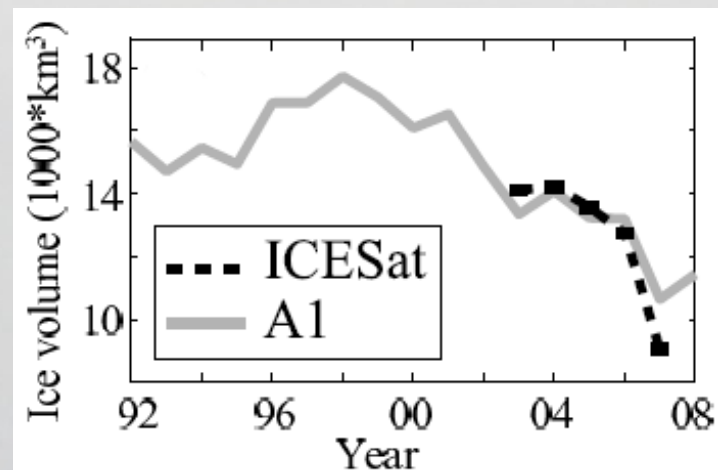
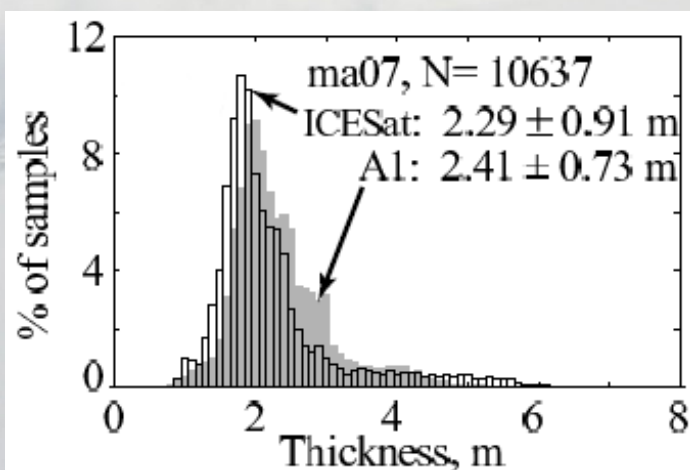
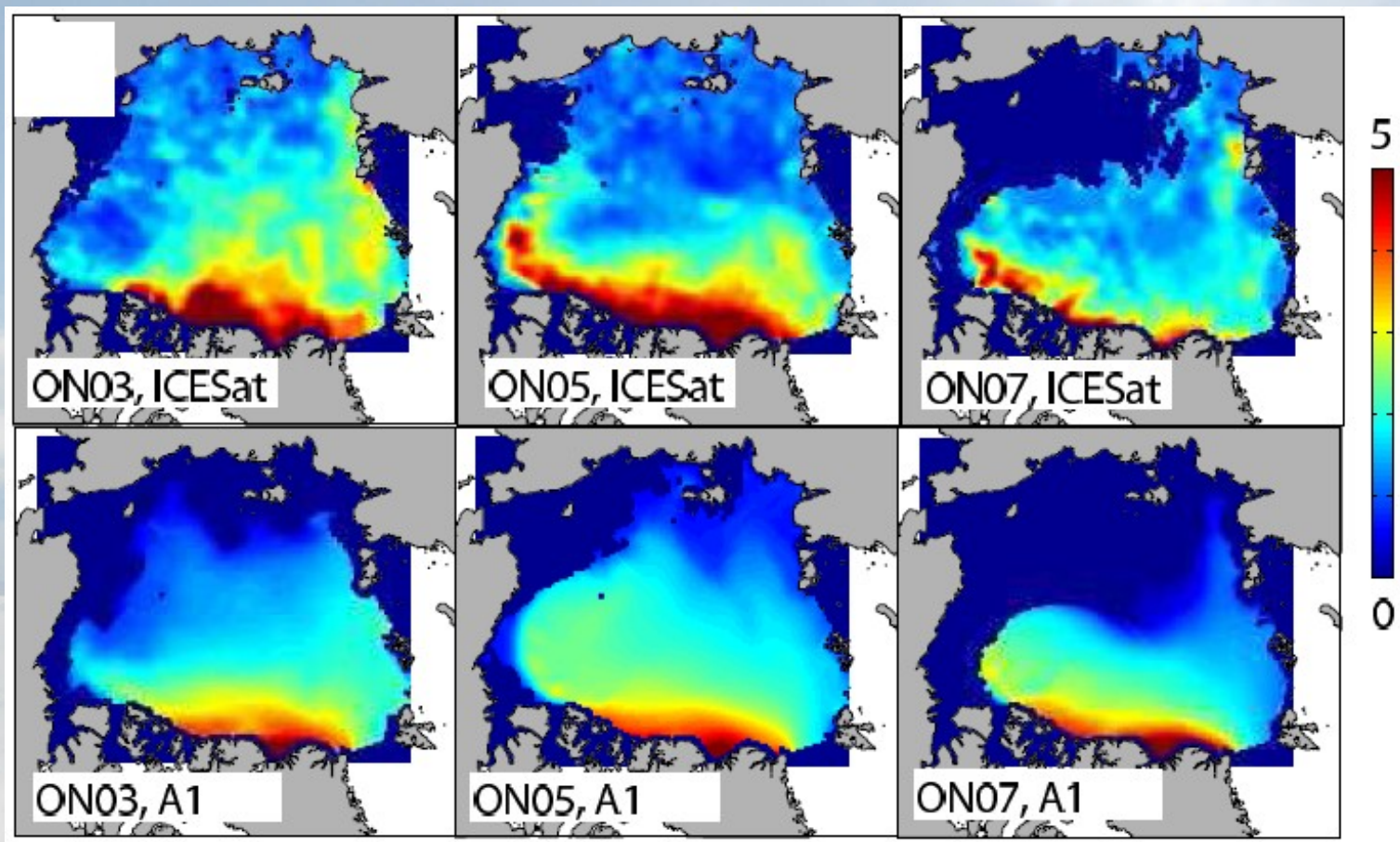
Velocity



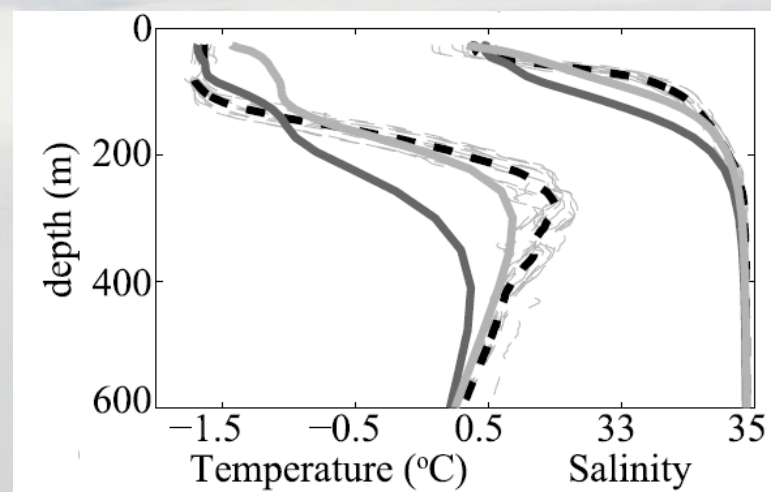
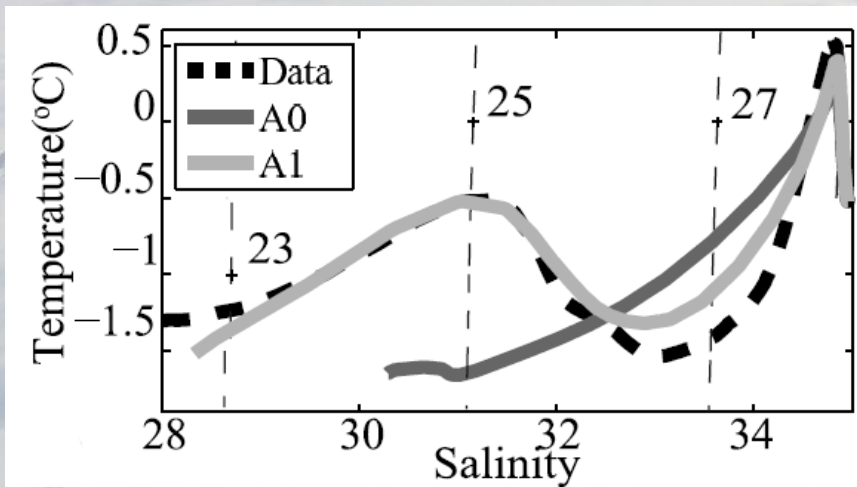
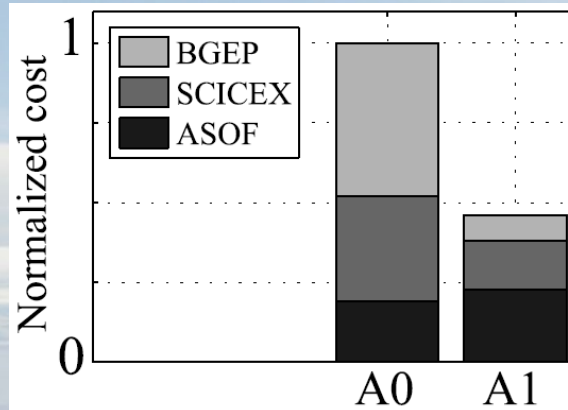
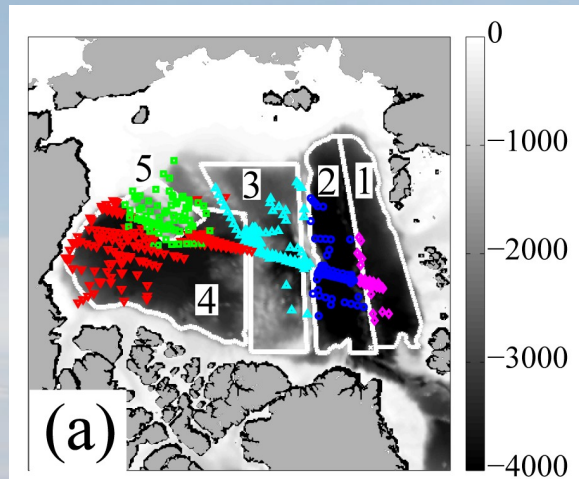
Flux



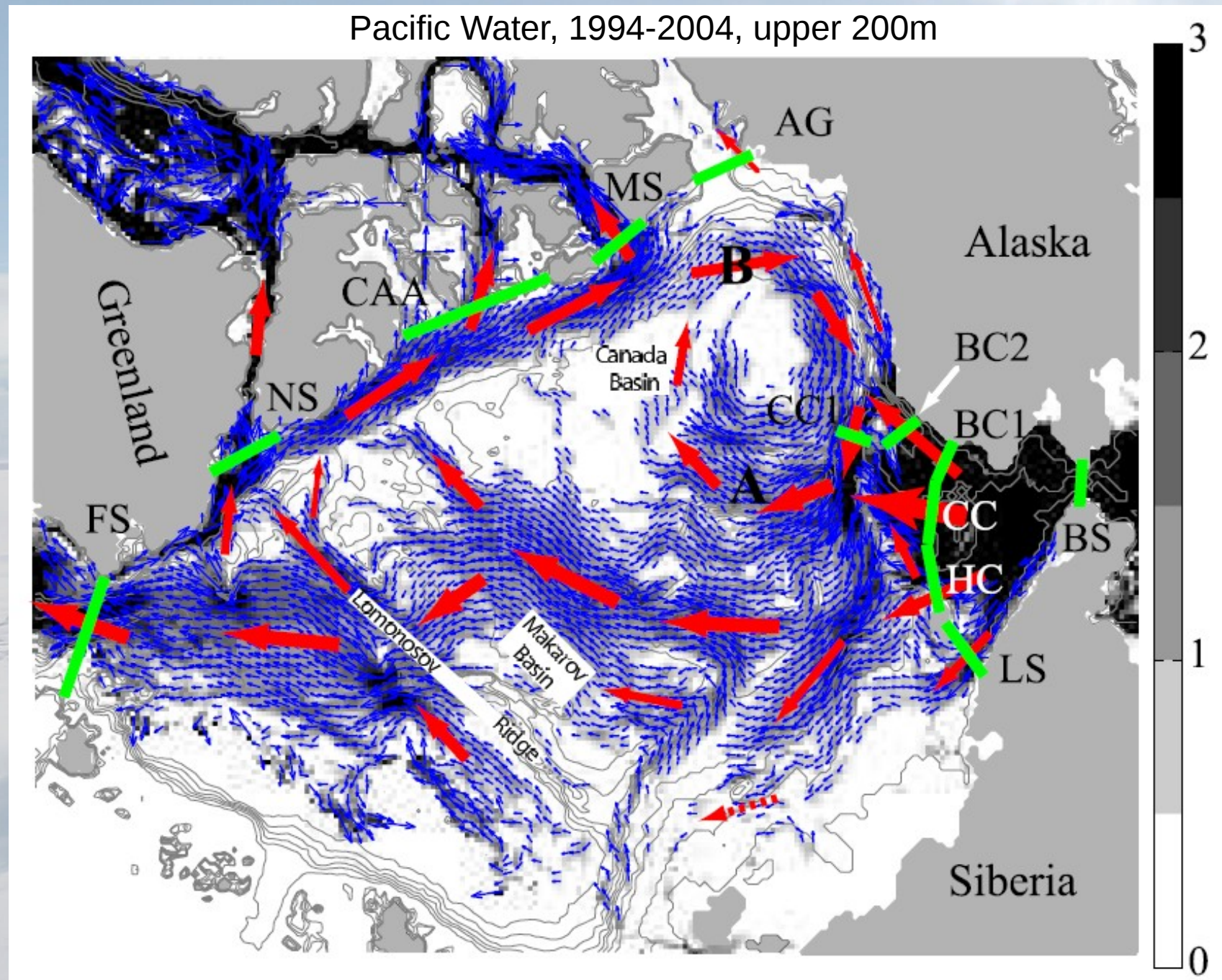
Results – sea ice thickness



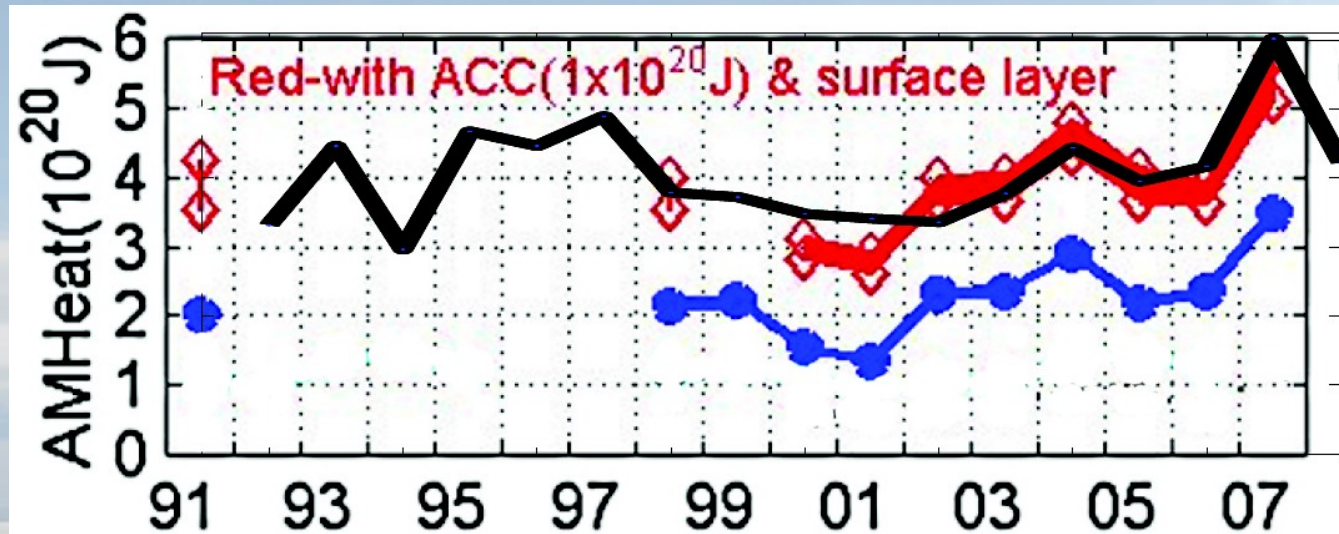
Results – hydrography



Results – circulation



Results - Transports



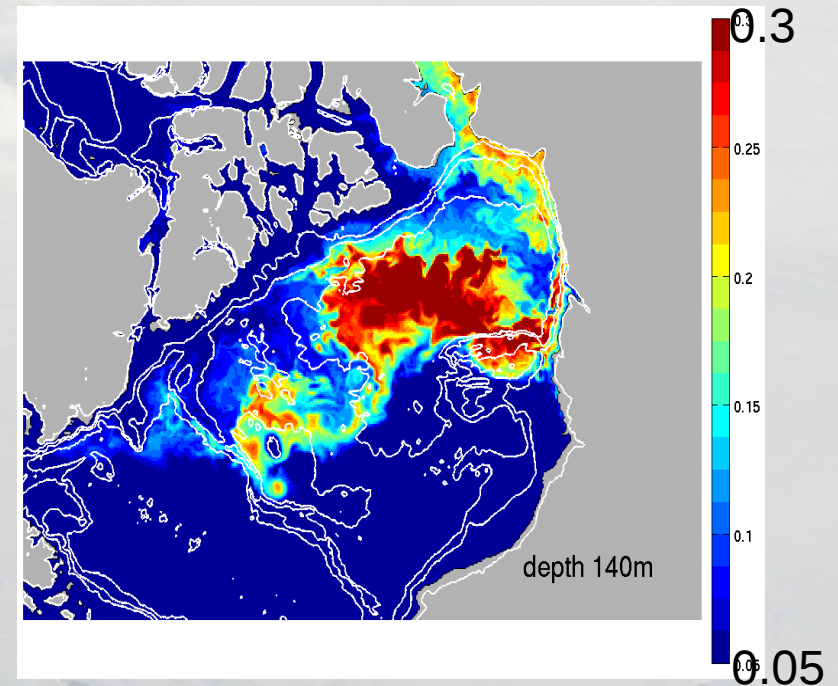
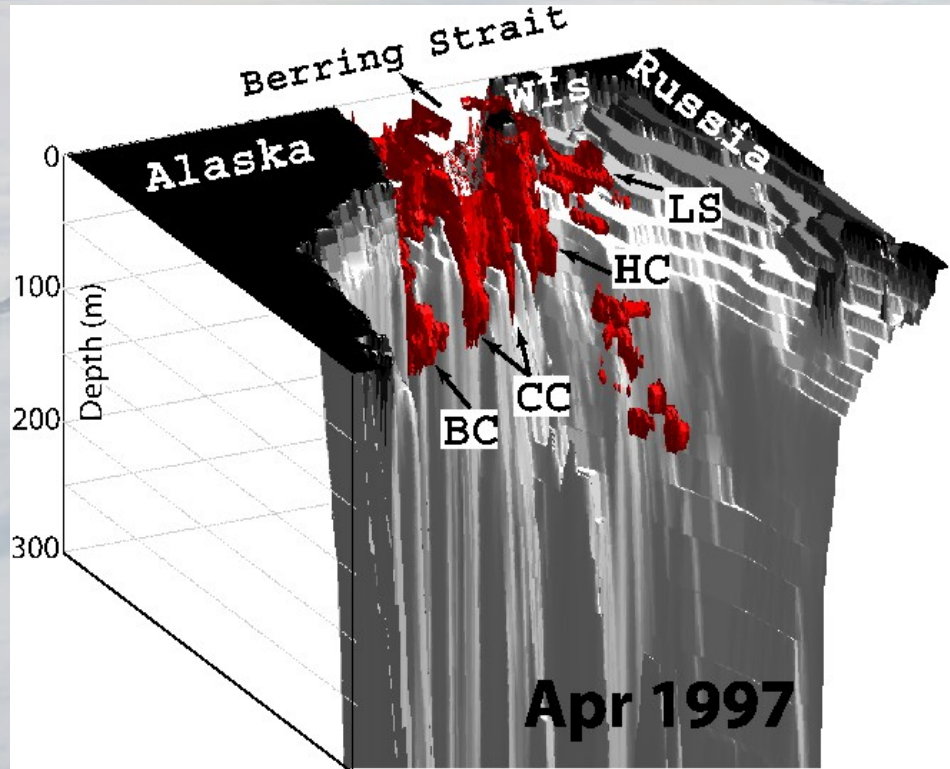
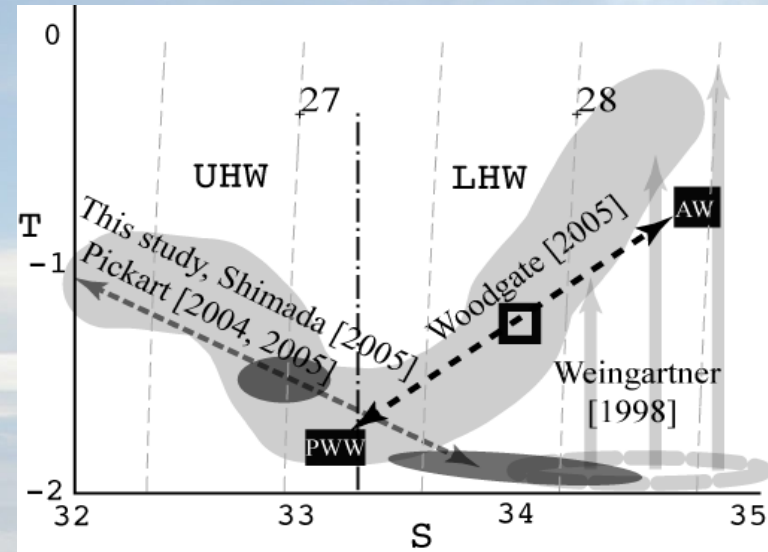
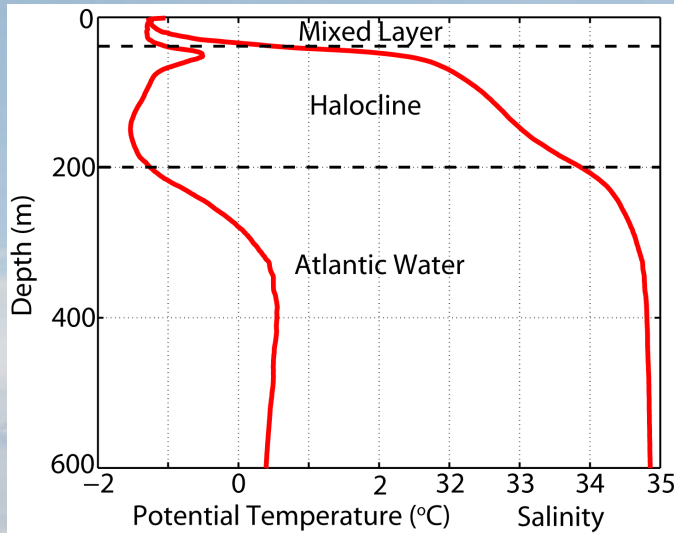
Woodgate [2005, 2006]

Release of Solution:

- Nguyen, Menemenlis, and Kwok, 2009: *Improved modeling of the Arctic halocline with a sub-grid-scale brine rejection parameterization*, J. Geophys. Res., 114, C11014, doi:10.1029/2008JC005121, 2009
- Nguyen, Menemenlis, and Kwok, 2010, *Arctic ice-ocean simulation with optimized model parameters: approach and assessment*, JGR-ocean, submitted.
- Nguyen, Menemenlis, and Kwok, 2010, *Formation of the Halocline in the Arctic Ocean*, manuscript in prep.
- Watanabe and Nguyen, 2010, *Wind-driven halocline variability in the Western Arctic Ocean*, JGR-ocean, submitted.
- Holloway et al., 2010, *Evaluating ocean models against 10,000 years of current meters observations*, JGR-ocean, manuscript in prep.
- Jahn et al., 2010, *Comparison of the Arctic FW budget and FW export variability simulated from different models*, JGR-ocean, manuscript in prep.
- Aksenov et al., 2010, *Tracing Pacific Water in the Arctic: AOMIP model experiments*, JGR-ocean, manuscript in prep.
- Proshutinsky et al., 2010, *Evaluation of Arctic sea ice thickness simulated by AOMIP models*, JGR-ocean, manuscript in prep.
- Clement et al., 2010, *On the flow through Bering Strait: A synthesis of model results and observations*, Book chapter in prep.

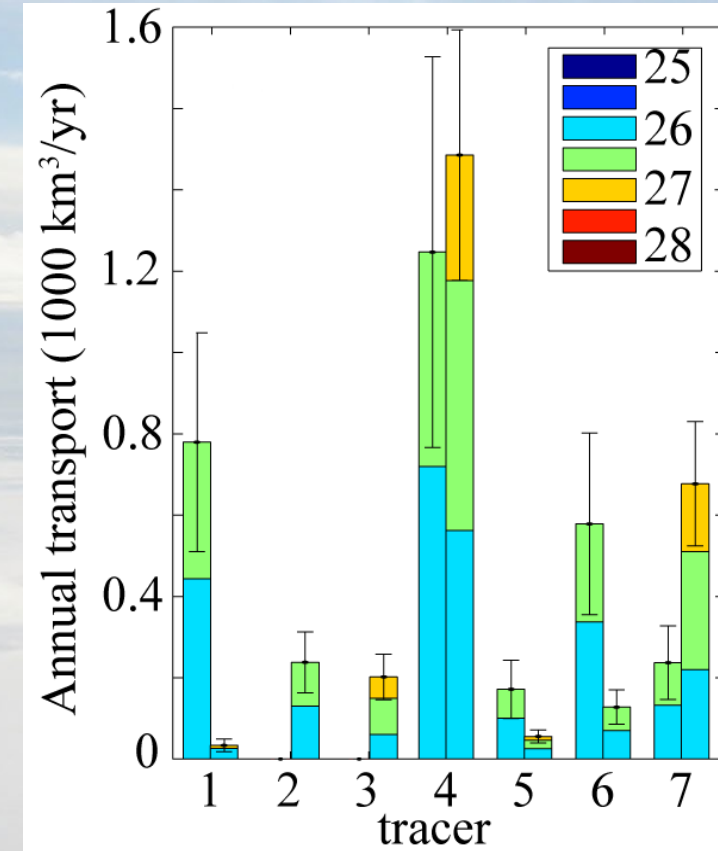
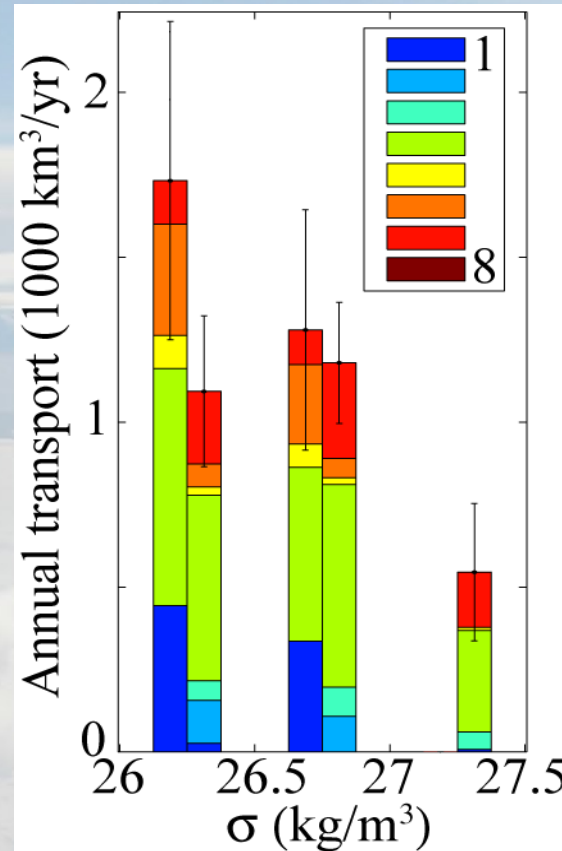
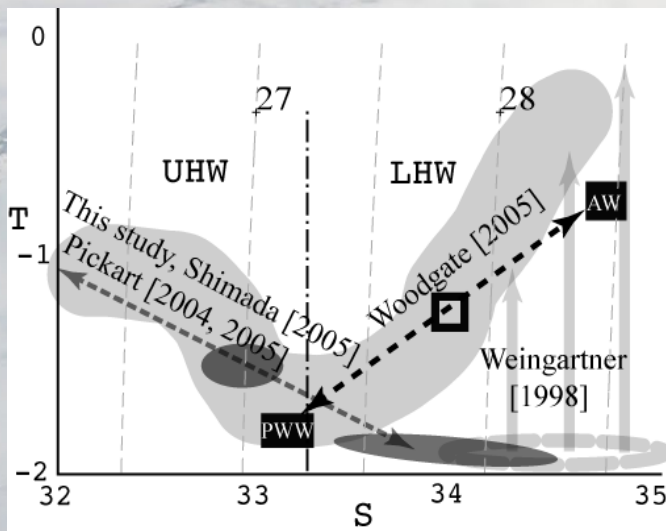
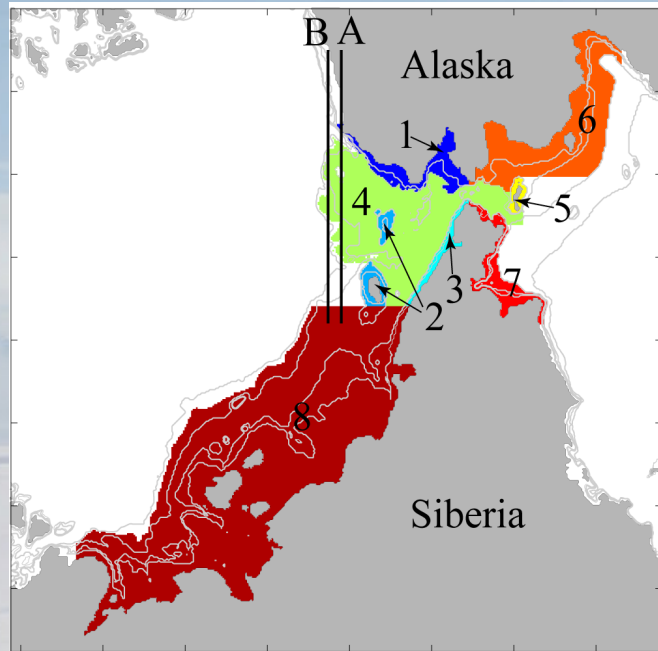
Process study example 1

Formation of the halocline in the Western Arctic Ocean:



Process study example 1 (cont.)

Formation of the halocline in the Western Arctic Ocean:



Annual mean: 5800 +/- 700 km³/yr

Ventilation Rate: ~ 8.5-17 years

if take Canada Basin ~ 10⁶ km² x [50-100]m [Pickart 2005]

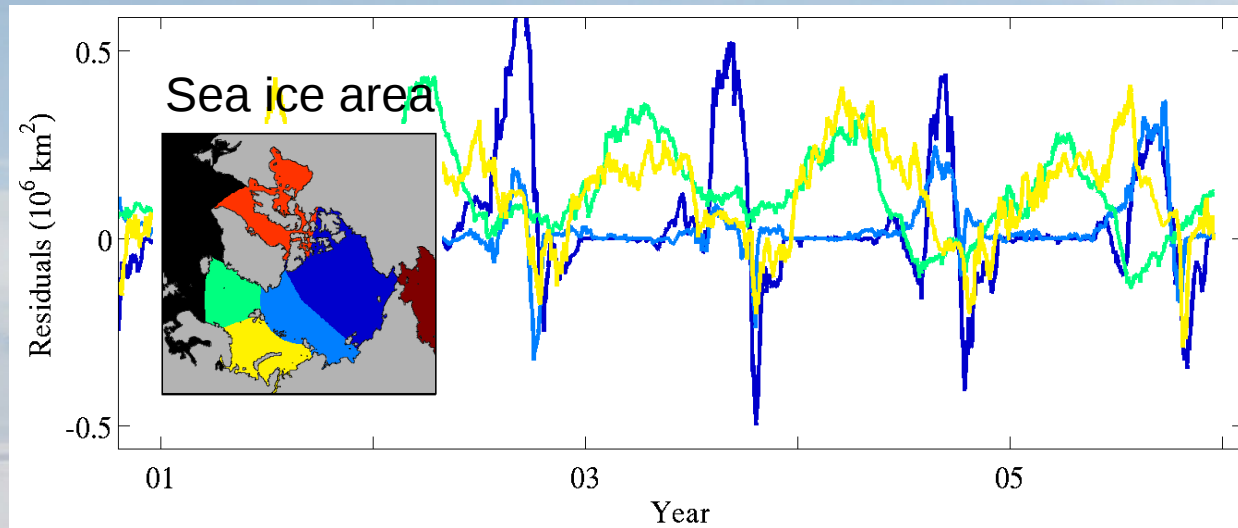
Consistent with Pickart [2005] estimate of 10-20 years

Summary

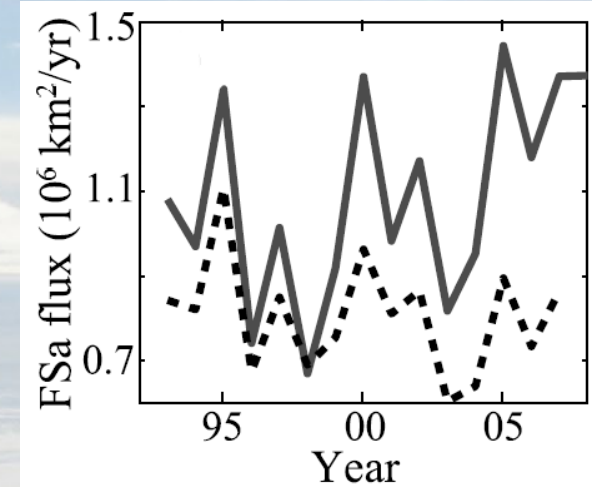
- Comprehensive optimization and assessment of a coupled ocean – sea ice Arctic Ocean solution
- Consistent with observations beyond optimization period
- Reproduce sea-ice conditions in recent years
- Reproduce sea-ice negative trends: volume, extent
- Reproduce water mass in the Western Arctic
- Offers a mean to identify systematic mis-representation of processes
==> e.g., Nguyen et al., [2009]
- Solution available to scientific community

Summary 2

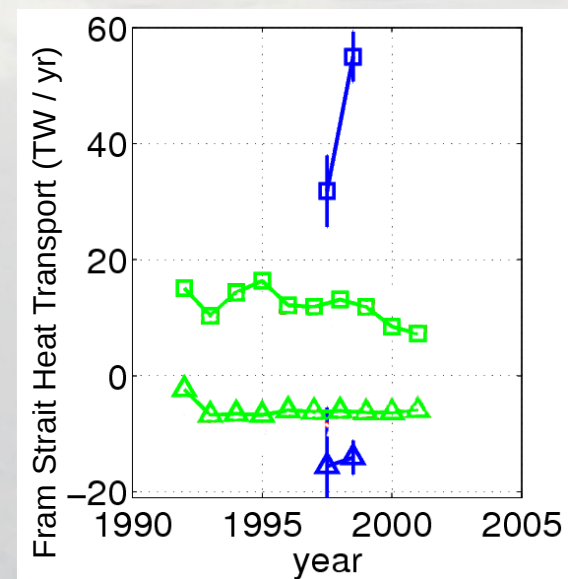
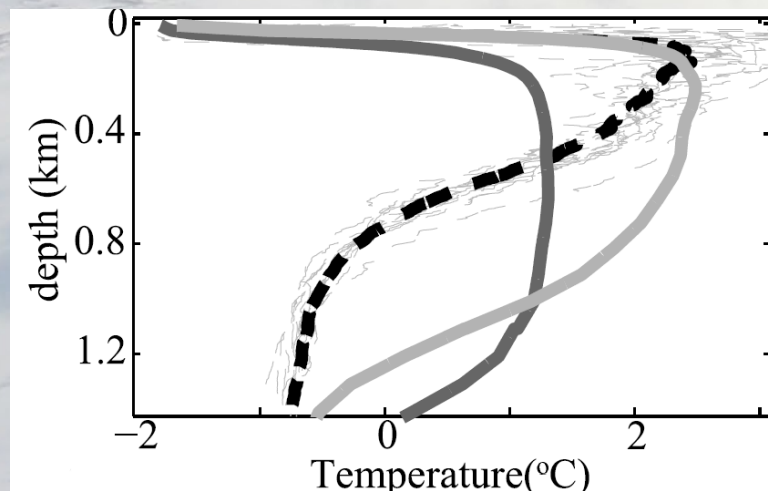
Systematic differences between data and model still persist:



Sea ice flux at Fram Strait



Atlantic Water



Adjoint solution:

Collaborative Research: An Eddy-Permitting Arctic & Sub-Polar State Estimate for Climate Research

NSF funded, PI: Patrick Heimbach,
Co-PI: Carl Wunsch, An T. Nguyen, Rui Ponte

Objectives:

- Production of an eddy-permitting Arctic and sub-polar North Atlantic state estimate (ASTE) for climate research
- Constrained by as many ocean and sea-ice observations as available and practical.
- Achieved through minimization of a least-squares misfit function (**adjoint**)

Initial Science Focus:

- Connection between deep water formation processes
- Atlantic meridional overturning
- Freshwater input at high latitudes and its pathways
- Interaction between Atlantic Water, Arctic halocline formation and sea-ice

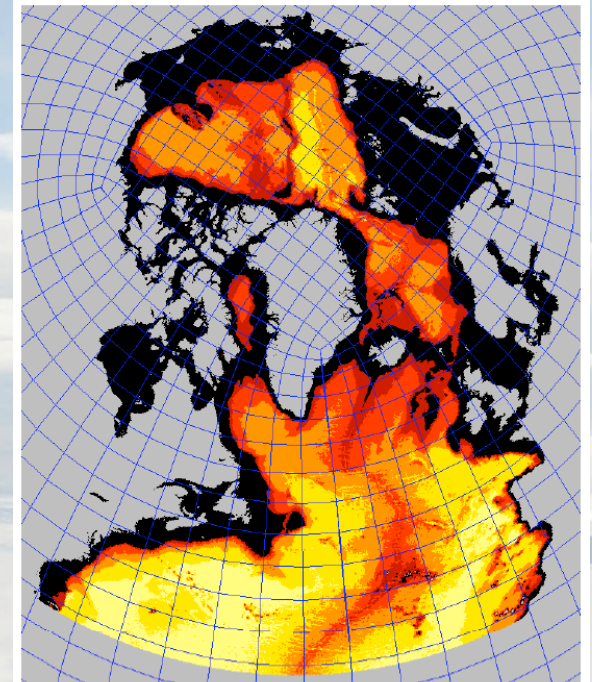


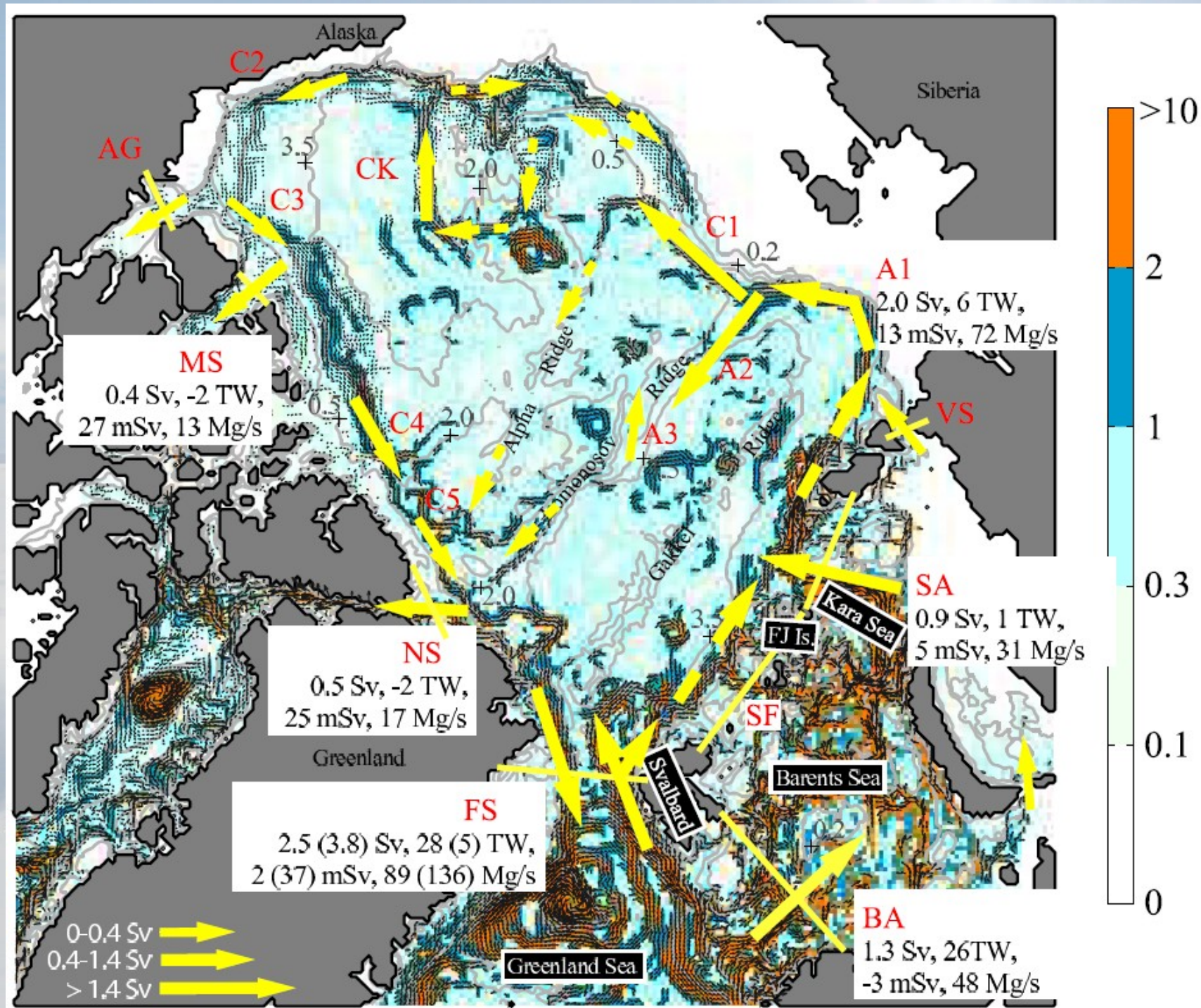
Figure 1: Bathymetry and model grid of ASTE.

Empty



Results – circulation

Atlantic Water



Least-square fits

$$\mathbf{y} = G(\boldsymbol{\eta}) + \boldsymbol{\epsilon}$$

$$\Delta \mathbf{y} = \mathbf{G} \Delta \boldsymbol{\eta} + \boldsymbol{\epsilon}$$

$$J = \Delta \boldsymbol{\eta}^T \mathbf{W}_{\eta} \Delta \boldsymbol{\eta} + (\Delta \mathbf{y} - \mathbf{G} \Delta \boldsymbol{\eta})^T \mathbf{W}_y (\Delta \mathbf{y} - \mathbf{G} \Delta \boldsymbol{\eta})$$

$$\widetilde{\Delta \boldsymbol{\eta}} = (\mathbf{G}^T \mathbf{W}_y \mathbf{G} + \mathbf{W}_{\eta})^{-1} \mathbf{G}^T \mathbf{W}_y \Delta \mathbf{y}$$

$$\tilde{\boldsymbol{\eta}} = \boldsymbol{\eta}_o + \widetilde{\Delta \boldsymbol{\eta}}$$